The Application of computer models for the integrated management of Water resources by CMA's and WUA's.

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Abstract

The average rainfall of South Africa is 495 mm, well below the world average of 860 mm, with only 35% of the country receiving more than 500 mm. Most drainage regions are over-exploited (Aquastat, 2005; NWRS, 2004). Against this background, a National Water Resource Strategy (NWRS) has been developed that emphasises sound water management by the various water-using sectors. Water for the Reserve is of the greatest priority, and if required water may be reallocated from other sectors to meet the requirements of the Reserve. With irrigated agriculture being the largest consumptive user of water in the country (NWRS, 2004), it is plausible that all viable water conservation and demand management options will be explored within the sector, from which water may be liberated due to increased water use efficiencies. In the event that water conservation and demand management options do not liberate enough water, it is plausible that water may need to be reallocated from all existing water using sectors, guided by the NWRS and Catchment Management Strategy (CMS).

The planning of irrigation water requirements, the day-to-day managing there-of and the control of water for irrigation areas and for river systems are complicated by nature. Unlocking water related efficiencies in systems is often not a straight forward task. A number of computer models have been developed to assist the irrigation planner and manager in their water management tasks. The models can also be used to assess the potential of various actions to improve water use efficiency within the irrigation sector. The models include: **SAPWAT**, a program for planning crop irrigation requirement. The model can help farmers and water resource managers to better understand the water requirements of a host of crops anywhere in South Africa. This information assists farmers to size their irrigation systems and schedules accordingly; **SWB**, an irrigation-scheduling model that calculates the daily water use and requirement of crops by simulating crop growth. Irrigation scheduling with SWB assists irrigators to apply the right amount of water at the right time, thereby utilising water efficiently, and reducing the leaching of nutrients; **WAS**, which consists of a number of modules to assist the WUA with administrative tasks as well as the ordering and releasing of water; **RISKMAN** an economic risk management tool which can be used by irrigators to select the most appropriate crop mix that offers the most appropriate level of return and risk for the irrigator; **ACRU**, a process based hydrological rainfall-runoff model for small catchments which can be aggregated for large systems. The model can allow, amongst other things, landuse and management practice scenarios to be simulated. This model may be very useful for WUAs, larger farmers and CMAs. The **MIKE BASIN** model is a catchment node-and-channel network model that is used to calculate the yield of systems for given user demand scenarios and river and reservoir operating rules. The model allows stakeholders to quickly and easily test the impact of various water use, and operating rule scenarios.

The objectives of this project are to introduce to key selected participants the already integrated models (WAS, RISKMAN and SWB in a GIS environment) and other models (SAPWAT, ACRU and MIKE BASIN) with the purpose of transferring the technology to these stakeholders. The intention of the technology transfer is for water resource managers and water users to better understand the hydro-socio-economic aspects of water management at different scales, including catchment, WUA, farm and field scale. If it transpires that the integration of the models presently outside the integrated GIS environment (SAPWAT, ACRU and MIKE BASIN) should be necessary, and if it should be practically possible, this integration will be attempted.

Case study areas have been selected on interest shown by the WUAs, their user needs, as well as their capacity. These include: Mhlathuze Catchment; Gamtoos WUA; Sunland WUA; Vaalharts; ORWUA; Lower Olifants and Loskop WUA.

Keywords: Irrigation Efficiency Management Planning Water-balance

1 Introduction

The average rainfall of South Africa is 495 mm, well below the world average of 860 mm. Furthermore, the fact that only 35% of the country, mainly the eastern parts, has a mean annual precipitation of 500 mm and 21% having an MAP of less than 200 mm supports the fact that South Africa is a water-scarce country. With the exception of some rivers on the eastern and southern coastal areas and the Orange River, all other rivers in the country are over-exploited (Aquastat, 2005). Against this background, a National Water Resource Strategy (NWRS) (RSA, 2004) has been developed under the 1998 National Water Act that emphasises good water management for all sectors that use water, and calls for an integrated approach to water resources management. Water resource managers are given the mandate to allocate water use entitlements in an equitable, sustainable and efficient manner. The NWRS (2004) clearly indicates that the Reserve is of the greatest priority and that, if required, water may be reallocated from other sectors to satisfy this demand. Water users are being encouraged to use water more efficiently, particularly in stressed catchments. With irrigated agriculture being the biggest consumptive user of water in the country (NWRS, 2004), it is plausible that it may be one of the first sectors to be targeted should water be required elsewhere. Irrigators are being put under increasing pressure to either improve the efficiency with which water is released from dams or into canals and applied via various irrigation systems to currently adopted land uses, or to seek new land use options which are more hydro-economically acceptable. For this reason it is imperative that the irrigation sector gets its house in order and improves the efficiency with which it uses water where possible. Improved efficiency may liberate water, without reducing levels of production and quality.

The planning of irrigation water requirements, the day-to-day managing there-of and the control of water for irrigation areas and for river systems are complicated by nature. Models that integrate hydrological and economic considerations are needed to support planning and operational undertakings by the irrigators and Water User Associations (WUAs). Over time a number of computer models have been developed, with funding by the WRC, in order to help the planner and manager in their water management tasks.

As such, the logical next step, and the purpose of this project, is to take the already developed models to stakeholders, and to transfer the technology to these potential users. The authors of this paper are currently involved in a three year WRC initiated and funded project, with co-funding received from the Department of Agriculture, and the Department of Water Affairs and Forestry, to promote the use, via a process of technology transfer, of a range of these models to enable Water User Associations and relevant Catchment Management Agencies to improve their water planning and management capabilities.

2 Models that provide assistance to the irrigation water manager

Several models have been developed with Water Research Commission funding. These include: **SAPWAT** for irrigation requirement planning; Soil Water Balance (**SWB**) for near real-time irrigation scheduling; Water Administration System (**WAS**) for water management at irrigation scheme level; **RISKMAN**, an economic risk analysis model and **ACRU**, a process-based hydrological rainfall-runoff model. The development of the **Mike Basin** model, a node-and-channel network model, was not funded by the WRC. However the WRC did fund a review of the model. Some of these models, namely WAS, RISKMAN and SWB have also been integrated and can run as a suite in a GIS environment.

2.1 SAPWAT

SAPWAT (Crosby & Crosby, 1999), as a planning tool for irrigation requirements, is to an extent based on the FAO CROPWAT model (Smith, 1992), but has been further developed on the basis of FAO Irrigation and Drainage paper 56 (Allen, et al., 1998). Some of these developments include the updating of crop characteristics tables to provide specific characteristics for different climatic regions and planting dates. The program uses long-term weather data, as well as summarised data of CLIMWAT (Smith, 1993) or similar data as a weather database for the calculation of reference evapotranspiration based on the Penman-Monteith approach. The 362 standard, automatic and CLIMWAT weather stations taken up in the program database for South Africa are shown on a map from where up to six stations can be selected simultaneously for comparison purposes. For each of the stations selected, the Penman-Monteith based reference evapotranspiration will be calculated with the weather data of this station and the result will be used in the estimation of irrigation requirements in conjunction with the four-stage crop factor curve, as described by Smith (1992) and later updated by Allen et al. (1998).

The application of SAPWAT as a planner of irrigation water requirements at scheme level has been field-tested and it has been shown that it gives credible and reliable results (Van Heerden, et al,. 2001). Application is seen to be at the level of the farmer, scheduling service providers, designers of irrigation systems and scheme planners, planners of irrigation water requirements, Water User Association (WUA) and Catchment Management Agency (CMA). The use of the model can enhance irrigation management efficiency by predicting how much water could be required for a specific period and thus enable both the farmer and the scheme management to order the required quantity of water timeously.

2.2 SWB

SWB (Annandale, et al., 1999) is a mechanistic model that integrates our understanding of the soil-plant-atmosphere continuum. It takes into account the supply of water from the soil-root system and the demand from the canopy-atmosphere system to describe crop water use. The Penman-Monteith reference crop evaporation (Smith, et al., 1996) together with a mechanistic crop growth model, which uses soil water and grows a realistic canopy and root system provides the best possible estimate of the soil water balance. It is based on the improved generic crop version of the NEW Soil Water Balance (NEWSWB) model of Campbell & Diaz (1988).

SWB gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop management data. It thus largely overcomes the problems of other models for irrigation scheduling. However, since SWB is a generic crop growth model, parameter specific data for each crop have to be determined.

For near-real time application, SWB needs to be linked to an automatic weather station.

Farmers with access to automatic weather stations can apply SWB. If the use of SWB is linked to soil water content monitoring by the farmer or through a scheduling service to the farmer, a more-or-less ideal situation of near real-time irrigation scheduling is possible. The real-time scheduling of irrigation can reduce the wastage of water, and can reduce electricity costs, leaching, and fertilisation costs, provided that irrigation system upkeep is up to standard, otherwise the potential advantage of near real-time irrigation scheduling could be negated by low system and application efficiencies

There are many forms of scheduling, the simplest being an irrigation roster which gives an irrigation recommendation for a given crop at a given time for a given area. Use is made of historical data sets of hydro-meteorological data to generate the rosters; therefore this type of scheduling is not near-real time scheduling. The recommendation is generally a volume and irrigation cycle. The volume may vary according to the growth stage of the crop. SWB is able to generate irrigation rosters, which are particularly useful to small farmers who do not have access to near-real time data. SWB can also be used for more comprehensive near-real time irrigation scheduling. The model, using near real-time hydro-meteorological data, and data related to the previous irrigation applications by an irrigator on a given field, is used to provide irrigation recommendations. It is quite possible to attain reasonable irrigation efficiencies with such approaches. However, managing water in such a way that the required amount is applied when it should be, such as where use is made of crop growth simulation models in conjunction with soil water measurement, should increase irrigation efficiency, resulting in an overall reduction in irrigation water use. Water freed in such a way, then becomes available for use elsewhere, either for more crops on the same farm of for use by other sectors of the water use fraternity. Although the number of farmers that currently use the more comprehensive irrigation scheduling option is relatively small, it is anticipated that due to increased pressures on the irrigation sector, which includes possible increases in the price of water, this type of scheduling will become more popular in the future, especially if the water trading market takes off, thereby incentivising farmers to use water more efficiently.

Water use efficiency stand on two legs. It is a combination of good irrigation scheduling combined with a system that is in good repair. If one of these is not up to standard, the one that is not up to standard negates any advantage that could result from having the other at a high level of efficiency.

2.3 WAS

WAS (Benadé, et al., 1997) is an integrated database driven system with many water management capabilities. The system consists of a few core modules including an administration model, an accounts module, a water request module and a water release module.

It can be implemented from a small water user association office that manages a few abstractions and measuring stations up to a CMA level that manages thousands of abstractions and measuring stations. Efficiency promoted by the model occurs at two levels. Firstly, as the system is a tailored for WUAs, it can quickly and easily help process a number of administrative tasks faced by WUAs, such as capturing and editing details of members, billing members, sending notices of outstanding payments etc. If the WUA is not efficient at handling its administrative matters, it will have less time to handle other aspects of its management which can help promote water use efficiency, such as policing water users, monitoring flows in canals and maintaining canals and drains. The WAS also allows water to be ordered more efficiently, and released appropriately in order to minimise losses, and to meet the demands of water users. Reverse routing equations are used for this purpose, and can help improve the efficiency of water releases in canals.

2.4 RISKMAN

Economic theory suggests that maximum production levels are not consistent with maximum profit if inputs are not free. Given farmers have the objective to maximise profits, Riskman can be used to evaluate the profitability of various crop and irrigation scenarios.

RISKMAN (Meiring et al., 2002) is a computer program that assists decision makers in selecting risk efficient irrigation schedules and areas planted to specific crops taking variable crop yields, output prices, hail damage and interest rates into account. This means that the model helps select crops and irrigation practices which offer the best returns over long periods. In some years the returns may not be as high as other options, but when a long period is considered, the farmer may get the best returns. Bankruptcies can be avoided, and banks can evaluate the riskiness of loans. Farmers and WUAs could also use RISKMAN to show that water is being used efficiently if a long-term view is taken. This applies to the hoarding of water rights to cater for dry periods. Risk associated with each of these variables can be characterised by means of empirical values, the triangular distribution or the normal distribution. The empirical distribution allows for an easy way to link outputs from crop growth simulation models such as SWB to enable the user to characterise risk of a specific irrigation schedule. The program is based on stochastic budgeting procedures that use Monte Carlo simulation to simulate risk. In order to simulate risk the cost items in the enterprise budget is classified as yield or area dependent. The model also allows for other costs to be specified. Since the simulations are done on a whole farm level the user has to input fixed cost and loan repayments.

The model is very flexible and the user can define alternative production management scenarios (area planted with specific irrigation schedule) to be compared in the risk analysis based on total margin above specified cost or net cash flow. Certainty equivalents are used to rank alternative production management scenarios. A certainty equivalent specifies the sure amount of money that makes him/her indifferent between the sure amount and the risky alternative. From the results it is also possible to calculate the risk premium a decision maker places on a risk efficient strategy compared to dominated strategies.

The model will most probably be used by agricultural advisors and leading irrigation farmers.

2.5 ACRU

ACRU is a daily time step process based hydrological rainfall-runoff model. The model can simulate the hydrological responses of different crops as well as different land uses and management practices. It can model “what if” scenarios, using long term observed hydro-meteorological input data, as well as soils information. In its current state ACRU is best used as a planning model. However, with a few extra developments, ACRU can be used as an operational model, making use of near real time, and even forecast data. The use of ACRU with forecast data may hold significant value to help catchments improve their water use efficiencies, in that future stream-flows could be predicted, which can help farmers in their cropping and irrigation decisions.

The model will generally be used by CMAs and WUAs, particularly to help in the formulation of the CMS (Catchment Management Strategy).

2.6 MIKE BASIN

MIKE BASIN is a node and channel network model, developed by the Danish Hydraulic Institute (DHI) and deployed around the world. It allows one to link water users with various water supply options (e.g. dams, rivers and groundwater sources). The network solver allows the model to accommodate various operating rules, including both the Priority-based River and Reservoir Operating Rule (PRROR) option, as well as the Fractional Water Allocation and Capacity Sharing (FWA-CS) option. This model is used to reconcile water supply with water demand, in order to work out how much water there is to allocate, and what various users’ assurances of supply are if they use water from certain water resources under various operating rules. Mike Basin is mainly used as a planning model, using long sets of historical flow data, with current or expected water demand patterns. It can however also link with Mike Floodwatch, which is in effect a database which captures near-real time data.

The model is particularly important to CMAs and WUAs, as the outputs of the model can assist in the assessment and formulation of water allocation strategies. Stressed catchments undergoing compulsory licensing may, in particular, have a high need for the use of the model. The Mike Basin model can operate on various time steps, including daily and monthly. ACRU could be used to generate the stream-flow sequences which are then fed into the Mike Basin model.

3 Planned technology transfer to WUAs

The objectives of this project are to introduce to key selected participants the already integrated models (WAS, RISKMAN and SWB in a GIS environment) and other models (SAPWAT, ACRU and MIKE BASIN) with the purpose of transferring the technology to these stakeholders. The intention of the technology transfer is for water resource managers and water users to better understand the hydro-socio-economic aspects of water management at different scales, including catchment, WUA, farm and field scale. The adoption of the models should lead to improved levels of water use efficiency, which is in the interests of WUAs and farmer members. If it transpires that the integration of the models presently outside the integrated GIS environment (SAPWAT, ACRU and MIKE BASIN) should be necessary, and if it should be practically possible, this integration will be attempted.

It is acknowledged that access to reliable data, required by the various models as input, is often quite hard to obtain. A key focus area of the project will be to collect or make available the data, and then validating the data if so required. The data, where possible, will be captured in a GIS, as the GIS is well understood by stakeholders, and will improve the willingness of stakeholders to adopt the models if they have links with the GIS. Due to the importance of GIS, and due to the fact that some of the research team has had limited exposure to GIS, one objective will be to build the capacity of the research team, and WUAs participating in the project, in this regard

At the completion of the project, means will be sought to transfer the technology in a suitable format to regions, WUAs and users not presently targeted. By the end of the project we hope to have transferred expertise to a few WUAs (which are randomly located throughout SA), and which have capacity. These WUAs can serve as nodes of expertise, from which other WUAs can learn. One objective of the TT project is for there to be a sustainable continuation of the use of the models. It is hoped that the WUAs forming part of the study will continue to use the models (with input from the developers when so required), as well as for the WUAs to share insights and expertise with other WUAs

An indication of success for this project will be the acceptance and adoption of the models by the selected participants. It is foreseen that the integrated models can be used to assist farmers both with land use and management practice planning, as well as to improve the efficiency of water releases and distribution at a near-real-time operational level.

The methodology to be followed can best be described with the following tasks that need to be undertaken in the course of the project:

- Exploratory overview and final selection of 5 to 7 irrigation schemes as study areas in consultation with WRC and DWAF;

- Engage end-users (staff of Water User Associations (WUA) and farmer representatives) on selected irrigation schemes to:
    - Explain the purpose of the Technology Transfer project;
    - Present different models for water management decision support;
    - Identify potential users and user needs;
    - Interact with end-users, obtain buy-in, and make final selection of participants;
    - Determine minimum data requirements for database;
    - Collect spatial information and install GIS;
    - Present information sessions on the integrated modelling approach within the context of the water supply system to target groups/end-users to demonstrate integrated application of these models in water management;
    - Determine user needs and requirements for water management from field to catchment level;
    - Determine which data are available for the identified schemes, decide how many and which schemes could be addressed within available funding;
    - Install appropriate combination of models for appropriate target groups e.g. WUA staff, farmer study groups and advisors/extension officers;
    - Populate database (collect/collate/verify data);
    - Test, evaluate and adapt integrated GIS and modelling system for implementation in water management;
    - Develop and present training courses for end-users (WUA staff, extension officers/advisors/farm leaders, etc);
    - Interact with end-users through workshops or information sessions to evaluate acceptance and effectiveness of the technology transfer;
    - Put in place a process for hand over and continuation i.e. formulate an exit plan.

4 Interim results

Case study areas have been short-listed. The selection was done according to interest shown by the WUAs, the user needs of the WUAs, as well as the capacity of the WUAs. As the sustained use of the models is a key objective of the project, relatively well-capacitated WUAs were selected. The shortlist includes: Mhlathuze Catchment; Gamtoos WUA; Sunland WUA; Vaalharts; ORWUA; Lower Olifants and Loskop WUA.

The research team has interviewed the WUAs, and has an improved understanding of the conditions under which they operate. The GIS component of the project, which involves (i) the capturing of ortho-rectified digital imagery captured at a 1m or 0.75cm resolution, followed by the (ii) capturing (annotation) of GIS layers valid to the project. The GIS layers of interest and associated attributes include:

- Property boundaries (polygon). Details of the owner, Postal address and contact number are captured. This information has links to the WAS system, and is very important for the WUA for general administration purposes.

- Irrigated land boundaries (polygon), with a description of the crop. A differentiation is made between cash crops and annual crops. Details of cash crops are not given, as the nature of the crop will change frequently. Details of permanent crops are given. Details are also given as to the nature of the irrigation system used. Details of the age and condition of the irrigation system are NOT captured. A note is made if detailed soils analyses have been performed for the lands. This will enable the research team to request this information at a later stage if it is available and if it is needed.

- Canals are captured, with details of chainages, shape, cross sectional properties, depth and slope (this information is used for the WAS model).

- Roads are digitised.

- Rivers, weirs, major off take points are also captured.

The GIS task is a time consuming task, and will be undertaken for the Loskop, Gamtoos, Sunland and Vaalharts WUAs. The Mhlathuze Catchment has some GIS data available from the DWAF “Verification of Existing Lawful Use” study, while the ORWUA has previously undertaken its own GIS survey, and Lower Olifants are not yet ready for GIS. At present GIS data capturing for Gamtoos has recently been completed, and is almost complete for Loskop. The GIS component should be fully completed by May 2006.

The immediate task ahead is to work in the WUAs where and when the data becomes available, allowing the research team to better understand the user needs of the WUA, and to build the capacity of the WUA with respect to the models.

References

Allen, R.G., Pereira, L.S., Raes & D. Smith, M., 1998. Crop evapotranspiration. FAO Irrigation and Drainage paper 56. FAO, Rome.

Annadale, J.G., Benadé, N., Jovanovic, N.Z., Steyn, J.M. & Du Sautoy, N., 1999. Facilitating irrigation scheduling by means of the soil water balance model. Water Research Commission Report No 753/1/99. Water Research Commission, Pretoria.

AQUASTAT, 2005. FAO's information system for water and agriculture. Website at http://www.fao.0rg - Aquastat.

Benadé, N., Annandale, J.G. & Van Zijl, H., 1997. The development of a computerized management system for irrigation schemes. Water Research Commission Report No 513/1/95. Water Research Commission, Pretoria.

Campbell, G.S & Diaz, R., 1988. Simplified soil-water balance models to predict crop transpiration. In: Bidinger, F.R. & Johansen, C., (eds). Drought research priorities for the dry land tropics. ICRISAT, India.

Crosby, C.T. & Crosby, C.P., 1999. SAPWAT: A computer program for establishing irrigation requirements and scheduling strategies in South Africa. Water Research Commission Report No 624/1/99. Water Research Commission, Pretoria.

Department of Water Affairs and Forestry, 2004: National Water Resources Strategy, First Edition. Private Bag X313, Pretoria, 0001.

Meiring, J.A., Oosthuizen, L.K., Botha, P.W. & Crous, C.I., 2002. The implementation of the FARMS sustem for management decision-making in irrigation farming. Water Research Commission Report No 894/1/02. Water Research Commission, Pretoria.

RSA 2002. Government Gazette No 23711. Pretoria.

Smith, M., 1992. CROPWAT, a computer program for irrigation planning and management. FAO Irrigation and Drainage paper 46. FAO, Rome.

Smith, M., 1993. CLIMWAT for CROPWAT, a climatic database for irrigation planning and management. FAO Irrigation and Drainage paper 49. FAO, Rome.

Smith, M., Allen, R.G. & Pereira, L.S., 1996. Revised FAO methodology for crop water requirements. *Proc. of the Int. Conf. on Evapotranspiration and Irrigation Scheduling,* San Antonio, Texas, USA. 133-140.

Van Heerden, P.S., Crosby, C.T. & Crosby, C.P., 2001. Using SAPWAT to estimate water requirements for crops in selected irrigation areas managed by the Orange-Vaal and Orange-Riet Water Users Associations. Water Research Commission Report No TT 163/01. Water Research Commission, Pretoria.